# 5G Communication: An Overview of Vehicle-to-Everything, Drones, and Healthcare Use-cases



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# 5G Communication: An Overview of Vehicle-to-Everything, Drones, and Healthcare Use-cases

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***Abstract*—Advances in technology are not only changing the world around us but also driving the wireless industry to develop the next generation of network technology. There is a lot of buzz building over the advent of 5G that will facilitate the entire planet through continuous and ubiquitous communication connecting anybody to anything, anywhere, anytime, and anyhow regardless of the device, service, network or geographical existence. 5G will also prove to be a paradigm shift including high carrier frequencies with massive bandwidths, having large number of antennas, and with extreme base station and device densities. In this paper, we investigate the potential beneficiaries of 5G and identify the use-cases where 5G can make an impact. In particular, we consider three main use-cases: Vehicle-to-Everything (V2X) Communication, Drones, and Healthcare. We explore and highlight the problems and deficiencies of current cellular technologies with respect to these use-cases and identify how 5G will overcome those deficiencies. We also identified the open research problems and provide the possible future directions to cope with those issues.**

***Keywords*—5G, V2X Communication, Drones, Healthcare,Ultra-Low-Latency, Ultra-High-Reliability.**

## I. INTRODUCTION

Advances in technology are not only changing the world around us but also driving the wireless industry to develop the next generation of network technology. Over the last 25 years, mobile technologies such as 1st, 2nd, 3rd and 4th generation have focused on improving the speed and efficiency of wireless networks, but still there are some distinct application areas where current wireless networks are struggling to deliver. These areas include V2X communication (and particularly Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication), wireless healthcare services, utility applications and industrial automation, consumer, virtual and augmented reality services, and primary broadband access services etc. [1, 2]. It is expected that the new technologies (5G) will investigate the issues within the aforementioned areas and will also address the performance criteria for low latency, high speed, enhanced reliability, peak throughput per connection, system spectral efficiency, connection and capacity density, and low power consumption [3, 4].

It is anticipated that 5G will be the main developmental technology that will lead to a step-change in the capability of mobile networks particularly around new radio access technology, higher frequencies usage, network re-architecting, antenna improvements (beam forming and massive Multiple-Input Multiple-Output (MIMO)), ultra-low-latency, and ultra-high reliability. A report published by Nokia Communication [5] claims that from 2020 to 2030 there will be an increase of 10K times more traffic that needs to be carried out through mobile broadband technologies. Such a huge volume of data traffic will lead to the design of 5G architectures in a way that will enable deployment in a new and higher frequencies band. Some other factors such as ultra-low latency (less than one millisecond), reduced power consumption and increased battery life in terms of smartphones, tablets and laptops will also be considered in the design of 5G architecture.

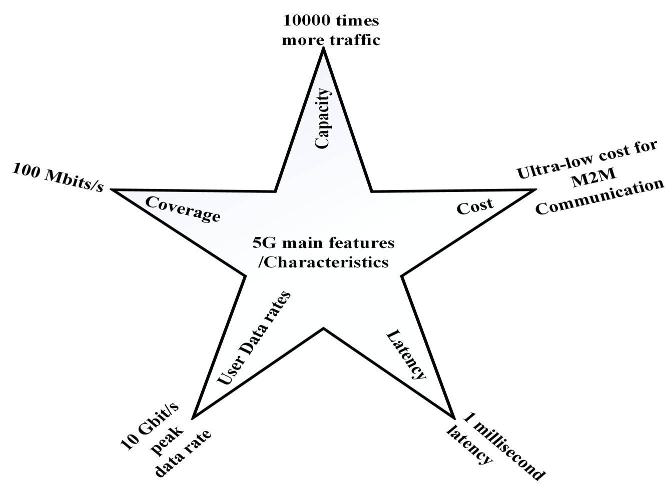


Fig. 1: Key Requirements for 5G Communication

An overview of the key requirements for 5G is summarised in Figure 1. Based on these requirements, we propose taxonomy of future potential 5G use-cases as: (i) Ultra-high reliable use-cases, (ii) Ultra-low latency use-cases and (iii) Ultra-reliable and low-latency use-cases. In terms of reliability, we identify disaster management using drones, and surveillance operations; in terms of low-latency, we explore the automotive industry (with a focus on assisted and autonomous driving), augmented/virtual reality, serious gaming, and smart grids; while in terms of both reliability and low-latency use-cases, we discuss healthcare and wearables, and industry automation.

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TABLE I: Acronym list

| Acronym | Definition | Acronym | Definition |
|---|---|---|---|
| V2X | Vehicle-to-Everything | V2V | Vehicle-to-Vehicle |
| V2I | Vehicle-to-Infrastructure | MIMO | Multiple-Input Multiple-Output |
| V2P | Vehicle-to-Pedestrian | IV | Intra-Vehicle |
| UAV | Unmanned Aerial Vehicle | LTE | Long-Term Evolution |
| mmWave | Millimetre wave | e-CAVs | Emergency connected and autonomous vehicles |
| r-CAVs | Regular CAVs | SF | Stable Fixtures |
| RFID | Radio Frequency Identification | OBU | On-board Unit |
| RSU | Roadside Unit | DSRC | Dedicated Short-range Communication |
| GPS | Global Positioning System | RAT | Radio Access Technology |
| WAVE | Wireless Access in Vehicular Environments | LTE-A | LTE-Advanced |
| OFDM | Orthogonal Frequency Division Multiplexing | ABS | Antilock Braking Systems |
| CAN | Controller Area Network | 3GPP | 3rd Generation Partnership Project |
| OFDM | Orthogonal Frequency Division Multiplexing | OFDMA | OFD Multiple Access |
| SC-FDMA | Single Carrier FDMA | IHSR | Intelligent Hierarchical State Routing algorithm |
| D2D | Device-to-Device | QoS | Quality of Service |
| ML | Machine Learning | AI | Artificial Intelligence |
| SNR | Signal-to-Noise Ratio | CBBA | Consensus Based Bundle Algorithm |
| IoT | Internet of Things | IoMT | Internet of Medical Things |
| PHY | physical | MBMS | Multimedia Broadcast/Multicast Service |
| eMBMS | Evolved MBMS | UMTS | Universal Mobile Telecommunications System |

The main contribution of this survey is to provide the reader with state-of-the-art technological trends in terms of 5G communication and highlight the limitations and problems of existing cellular technologies. We consider three main future use-cases of 5G communication: V2X communication, drones, and healthcare. In terms of V2X communication, we present an exhaustive review of the up-to-date research progress with respect to V2V, Vehicle-to-Pedestrian (V2P), V2I, and Intra-Vehicle (IV) communication along with their key application areas. We also identify the key limitations of existing technologies in all of these sub-use-cases of V2X communication. Similarly, in terms of drones, first we provide an overview of single Unmanned Aerial Vehicle (UAV) deployment, multiple UAV deployment and collision avoidance. Then we present some of the key application areas of drones for critical infrastructure development using 5G communication. A comparative analysis of control latency in terms of 4G and 5G communication is also presented to inform the reader of the latest trends. Finally, in terms of healthcare, we mainly consider online consultation, online health monitoring, remote diagnosis of time-critical medical events and mobile robotic surgeries. Table I provides a list of the acronyms and their corresponding definitions that have been used throughout the paper.

The rest of the paper is organised as follows: Section II provides a literature review of the existing work. Section III investigates V2X communication, Section IV considers drone applications, Section V addresses the healthcare use-case, Section VI provide an overview of the open research challenges and future directions, while Section VII draws the conclusions.

## II. Related Work

Masini et al. [6] provide an overview of economic motivations, requirements, and enabling technologies along with the important international rules and regulations for short-range V2V-based vehicular networks and on-board vehicles connectivity respectively. The authors mainly concentrated on four different aspects to differentiate their work from others in the same area i.e. short-range V2V-based applications, design choices and factors for wireless enabling technologies, economic motivations for on-board wireless technologies and mandatory international rules for on-board connectivity. Simi-

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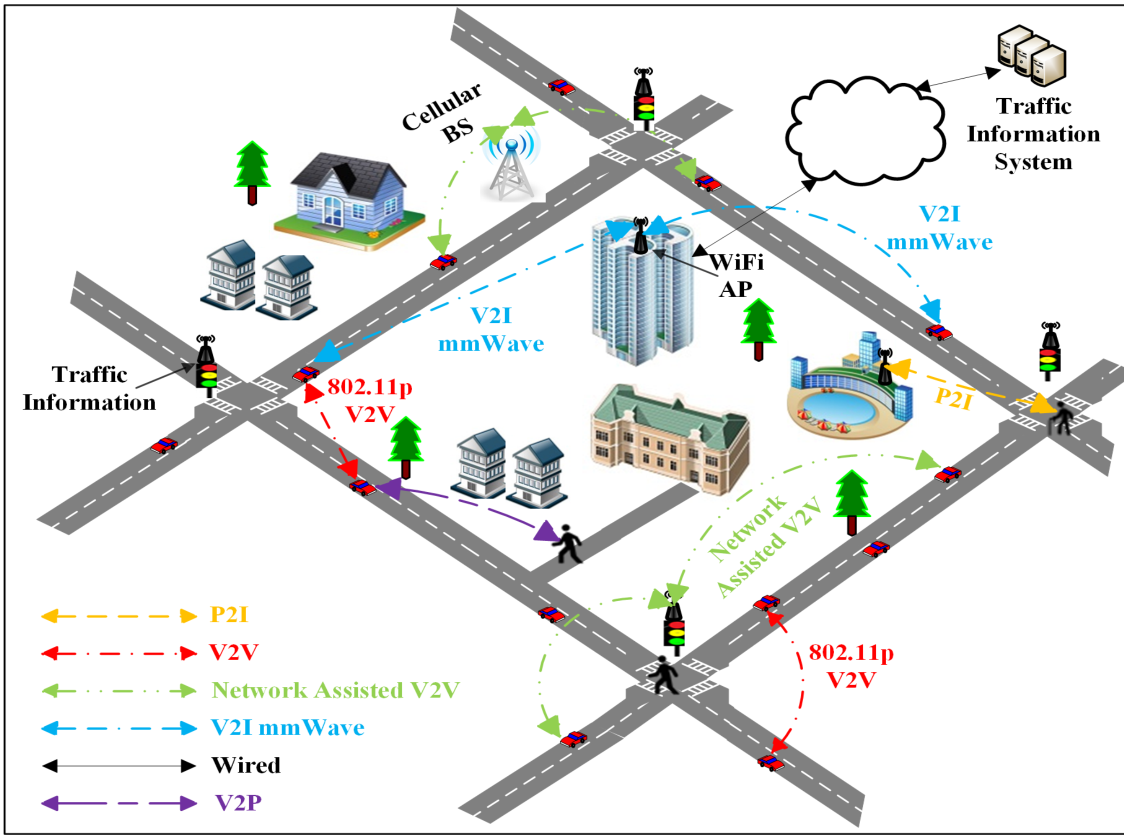


Fig. 2: V2X Communication Infrastructure using different technologies

larly, in [7], the authors analysed the requirements and use-cases in terms of 5G V2X and identified the gaps of the existing communication technologies. The authors also provide guidelines on how the existing and 5G technologies will try to overcome those gaps.

In terms of drone communication, Shakhatreh et al. [8] present a survey on the UAV challenges including charging, collision & swarming, and network & security with respect to civil applications. The authors highlighted different open issues and provide the possible ways of how these issues can be approached. Moreover, in [9], the authors provide an overview of 5G technologies that can be incorporated in UAV communication. 5G and UAV integrated architectures for space-air-ground scenario were presented and a variety of open research challenges were identified. Based on this integration, the authors also provide a state of the art overview of the research progress at different layers (physical layer, network layer etc.).

Furthermore, with respect to healthcare use-case, Darrell M. West [10] provides an overview of how 5G differs from earlier generations and highlights how 5G will make an impact in healthcare applications. The author investigated how 5G will enable new systems of care delivery, and how the application areas like imaging, diagnostics, and treatment can be improved through 5G to provide quality healthcare facilities to the people. Also, in [11], the authors presented how 5G and other technologies (Internet of Things (IoT), Artificial Intelligence (AI), and big data) will revolutionise healthcare system and provide an overview of how Machine Learning (ML) algorithms can be integrated with healthcare systems to detect the anomalies and to ensure that no medical problems has occurred. The authors also investigated how remote consultation and remote surgery can be enabled through telemedicine and e-health.

All of the above and many other surveys discuss the overall technological trends and their limitations in terms of V2X, drones and healthcare, but none particularly concentrates on limitations of existing cellular technologies. Also, in many surveys only a single use-case is discussed along with their limitations and future directions, but no survey considered more than one use-cases in the same paper. The main purpose of this work is to identify limitations of the existing cellular technologies and to provide a possible solution for each of these limitations in terms of V2X, drone communication and healthcare. Similarly, we consider three main use-cases of 5G communication instead of just one use-case. To the best of our knowledge, our work is the first to provide a comprehensive survey on three main use-cases of 5G in order to identify the problems of current technologies and to suggest the possible solutions based on 5G communication.

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## III. Vehicle-to-Everything (V2X) Communication

According to a report published by the U.S. Department of Transportation and National Highway Traffic Safety Administration in [12], 37,461 people were killed in motor vehicle crashes in 2016, an increase of 5.6% and 14.4% when compared to 2015 and 2014 respectively. Similarly, according to the UK Department for Transport [13], a total of 27,130 people were severely injured in road accidents out of which 1,710 lost their lives. On the other hand, traffic congestion is investigated by Texas A&M Transportation Institute in a report published in [14], and according to their investigation, the total delay time will increase to 8.3 billion hours by 2020 resulting a congestion cost of almost 192 billion U.S. Dollars. To address these issues, new solutions with high reliability and low latency are required that can use the currently available resources in an efficient way in order to save lives, reduce congestion and lessen the negative impact of transportation on the environment.

V2X communication mainly refers to the set of standards and technologies that will enable the vehicles to interact with the current infrastructure including roads and road users. An overall architecture of V2X communication based on 5G technologies is shown in Figure 2. These will potentially be based on tested networking protocols and technologies rather than relying exclusively on the hardware [15, 16]. Boban et al. [7] proposed an architecture for V2X communication based on future 5G technologies. The authors claim that the proposed architecture can lead to an accident-free connected automated driving and can fulfil the requirements for all V2X use case categories. In the following sub-sections, we will elaborate different cases of V2X communication with respect to challenges faced in 4G Long-Term Evolution (LTE) and will address the absolute solutions enabled by 5G technologies.

### A. Vehicle-to-Vehicle (V2V) Communication

Driverless and autonomous cars have increased in popularity because of their increased applicability for commercial and emergency services. In order to fulfil such services, connected and autonomous cars/vehicles require continuous access to sensory data from which the cars can perform advanced trajectory planning and complex high-speed manoeuvres [17]. For short-term trajectory decisions, the car can use on-board sensor information, but for long-term decisions, the car needs data and information from vehicles in near proximity. Hence, the exchange of sensor data is an important factor that requires a reliable connection between vehicles subject to strict quality-of-service (QoS) constraints [18, 19].

According to Lu et al. [20], connected vehicles are wireless connectivity-enabled vehicles that can communicate with each other and with the infrastructure, establishing interactions between vehicle-to-sensor on-board, vehicle-to-vehicle, vehicle-to-road infrastructure, and vehicle-to-internet. Based on these interactions, the vehicles can take safe dynamic decisions, can enhance their situational awareness, and can provide an information-rich and safer environment to other motorists and/or pedestrians. In [17], the authors propose a multi-link association scheme for millimetre wave (mmWave) V2V communication in order to better utilise the channel and to prioritise sharing the sensory data for emergency connected and autonomous vehicles (e-CAVs). By using the same method, the authors also address the issue of obstacle avoidance manoeuvres and advance trajectory planning in terms of e-CAVs as compared to regular CAVs (r-CAVs). Also, the Stable Fixtures (SF) matching game technique is proposed to formulate a more comprehensive many-to-many link association scheme establishing bidirectional links based on unique characteristics of each connected vehicles. The SF problem originates from a practical situation, where players play against each other in a chess tournament in order to construct a set of fixtures having different matches. Each match has two players, and a player can be involved in more than one match while fulfilling the condition that he/she cannot exceed their stable capacity [21].

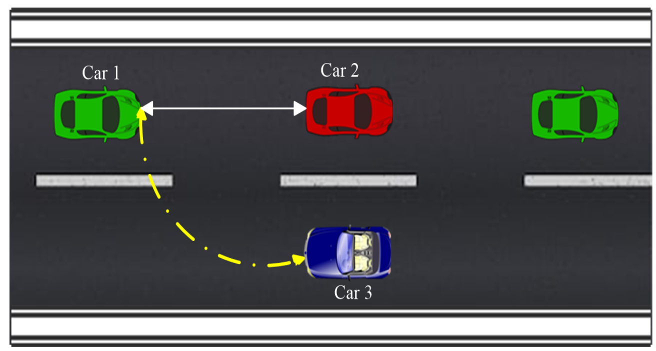


Fig. 3: Lane-Changing Process

Similarly, Chen et al. [22] propose rough set theory to formulate the lane-changing rules to enhance the decision-making process of autonomous vehicles in a complex urban environment, to reduce the influence of week interdependency data and to extract the driver's decision-making rules. The system was designed over a virtual urban traffic environment using Prescan simulation software developed for advanced driver assistant systems and intelligent vehicle systems [23]. A general overview of the car-changing process is shown in Figure 3, where the green car (Car1) is the subject Car that wants to change lane, while Car2 and Car3 are the interfering cars. Based on simulation results, the authors concluded that the Car1 driver's decision-making behaviour during the lane-changing process is subject to the relative distance between the subject car and the interfering Car3, and the relative velocity between the subject Car and the leading Car2.

Some of the key application areas of V2V communication are discussed as follows: V2V communication enhances driving safety and traffic efficiency along with information or entertainment provision to drivers in a number of use-cases such as traffic safety, traffic efficiency, infotainment and payments etc. In terms of traffic safety, V2V communication disseminates warning messages on several occasions e.g. entering intersections or departing highways, hazardous locations such as reporting accidents ahead, and obstacle discovery, forward collision and pre-cash warnings, and favouring police cars, fire fighter vehicles, and ambulances [24, 25].

Similarly, in terms of traffic efficiency, V2V communication enhances the route guidance and navigation system, automating traffic intersection control, optimising the green light speed, and providing information about variable speed limits. This will help to reduce traffic congestion and will lead to reduce the energy consumption [24, 26]. Moreover, infotainment and payment services such as on-board internet access, toll collection and parking payment etc. provide comfort services to the vehicle owner and also avoid congestion caused by toll collection.

### B. Vehicle-to-pedestrian (V2P) Communication

V2P is one of the most important applications of vehicular networks providing safety to pedestrians through wireless communication. Bagheri et al. [27] addressed the issue of V2P communication in order to improve the safety of pedestrians. The authors proposed a method based on the existing infrastructure that enables the development of V2P road safety applications. On pedestrian side, 3G and LTE were utilised as cellular technologies to provide connectivity to the individual's smartphone, while on vehicular side, an on-board SIM card was used for same purpose. In case of any issue with on-board SIM, driver's smartphone was considered as an alternative for connectivity purposes. The proposed adaptive multi-level approach was designed based on mobile cloud computing to compute and process all the data. Road users including vehicles, pedestrians and cyclists send updated messages containing speed, location and direction information to the cloud-based server. Two types of safety messages were identified: (i) cooperative awareness messages which are time triggered (periodic) beacons that carry position information and (ii) decentralised environmental notification messages which are event triggered and carry hazard warnings [27, 28]. In situations that are risky and may lead to a collision, road users will send updated messages in a periodic fashion at 100ms intervals. The authors conclude that their proposed method provides a risk-free environment for pedestrians and could also reduce the energy consumption of user equipments.

Similarly, Rahimian et al. [29] examined how the action of a pedestrian engaged in composing or reading an SMS can be influenced by sending mobile device warnings when approaching to an unsafe road crossing. The authors specifically assess the effects of texting on pedestrian road crossing behaviour and the effectiveness of those warnings in reducing unsafe road crossing. They project that texting reduces pedestrian awareness of traffic and prejudices their road-crossing decision-making. Warning alarms help redirect their attention towards traffic and also reduce the probability of risky road crossing and collision. The authors use an approach entitled "Between-subjects design" considering three different types of conditions: (i) texting, (ii) warning, and (iii) control. In terms of texting, the participants continuously receive and respond to the text messages during the entire road-crossing session, while in the case of warning, the participants also receive an auditory alarm from a cell phone when they enter to a situation that is classified as unsafe. In the control condition, the participants neither receive any text nor respond to any message but hold the smartphone during the entire road-crossing session. The authors conclude that the proposed technique improves road-crossing decisions of pedestrians which are busy in text messages. They also indicate that further investigation is required in situations when the participants receive the warning messages, but fail to respond to those messages, and continue to cross roads in an unsafe manner [29].

Moreover, in [30], the authors assessed the performance and effectiveness of a vibrotactile wristband device by helping older pedestrians in safer street-crossing decisions. The study was conducted in a simulated two-way traffic environment with a street-crossing task where twenty younger-old (age 60-70), twenty older-old (age 70-80), and 17 younger adults (age 20-45) with and without a vibrotactile wristband participated. The test was run on a virtual platform to check the device's ability to accurately emulate all the required communication between the vehicle, infrastructure and pedestrian. The authors claim that the haptic device partly compensates for some age-related gap-acceptance difficulties and reduces the street-crossing risks for all users. They also conjecture that the device will be beneficial for all ages but particularly for older participants and specifically for older women who have difficulties in street-crossing. The device also helps to reduce the number of decisions that may lead to collisions in situations when vehicles approach rapidly [30].The authors advise some educational and training programs by using virtual reality tools to educate pedestrians about their vulnerabilities and how to cope with those in order to reduce crash statistics [31–33].

### C. Vehicle-to-Infrastructure (V2I) Communication

Vehicle-to-infrastructure (V2I) is basically a communication model that allows a vehicle to share information with roadside components such as Radio Frequency Identification (RFID) readers and cameras, traffic lights, lane markers, streetlights and parking meters etc. V2I is a bidirectional wireless communication where data is transferred from infrastructure to vehicle and vice versa over an ad hoc network [34].

According to Péter, [24], some of the key components for a minimal V2I system should contain: Vehicle on-board unit (OBU), Roadside Unit (RSU), and a safe communication channel. OBU is comprised of a radio transceiver such as a dedicated short-range communication (DSRC) system, a GPS system and a processor and facilitates communication between the vehicles and RSUs and other vehicles in the near proximity. RSUs are composed of the same radio transceiver i.e. DSRC, an application processor and an interface to the V2I communication network. These are usually mounted on interchanges, intersections, and patrol stations. RSUs are mainly responsible for private data transfer and message prioritisation management to and from the vehicle. Messages are prioritised based on their criticality - local and V2V safety applications have the highest priority, public and private network applications have lower priority, while entertainment messages have the lowest priority [24].

Similarly, Ndashimye et al. [35] conducted an extensive survey on the effectiveness of V2I communication in the

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context of 5G networks that supports the co-existence of multi-tier heterogeneous wireless networks with various radio access technologies (RATs). The authors initially studied the V2I communication standards such as DSRC derived from the 802.x family, Wireless access in vehicular environments (WAVE), and LTE-A. DSRC uses a licensed spectrum at 5.9 GHz with seven channels of 10 MHz bandwidth (5.850-5.925). Out of the seven channels, the control channel in the centre is dedicated for safety applications, two at the end are reserved for special purposes, while the rest are the service channels available for both safety and non-safety applications [36, 37]. WAVE or IEEE802.11p integrate both the MAC and physical layer, use orthogonal frequency division multiplexing (OFDM) in order to divide the signal into multiple narrowband signals and define two classes of devices: OBU and RSU [36]. The authors also mention some of the key application areas of V2I such as traffic efficiency and management, entertainment and personalised applications and safety-related applications. The primary focus of the study is V2I safety applications that may lead to either reducing or even avoiding crashes by increasing driver awareness via different warning messages wirelessly communicated between vehicles and roadside infrastructure [35]. Some of the key recommendations from the proposed studies are: (i) efficient network discovery, (ii) underlying network selection, (iii) seamless and reliable vertical handover, (iv) QoS requirements, (v) dissemination of data, (vi) security and (vii) an upper layer communication protocol suite in order to support seamless vertical handover in 5G heterogeneous network environments.

Moreover, Ndashimye et al. [38] propose a network selection method that applies the knowledge of mobility data and network load information in order to carry out an effective handover for V2I communication over multi-tier heterogeneous networks. Some of the key parameters such as relative direction index, residence time index, proximity index, and network load index are identified in order to select the best candidate network for vehicle with a judicious coverage. The algorithms were tested in an OPNET simulator by developing a dual mode vehicle OBU fortified with both Wi-Fi and LTE-A cards in order to evaluate and validate the proposed system model. The performance of the proposed model was compared with the conventional method and access network discovery and selection function-assisted handover methods. The authors concluded that the proposed approach can reduce the unnecessary handover up to 50%, mean handover latency up to 40%, higher throughput up to 50% and lower end-to-end delay up to 43% with respect to the conventional handover method.

### D. Intra-Vehicle (IV) Communication

Wireless interconnections between sensors and other devices within the vehicle, such as sensors for detecting road conditions and driver's fatigue, monitoring tyre pressure and water temperature in the cooling system and advanced sensors for autonomous control are currently being investigated [20, 39]. Along with these, a number of other sensors and processors such as Antilock Braking Systems and Electronic Stability Control monitor a vehicle's internal performance and dynamics, while camera, radar, and ultrasonic sensors sense the environment around the vehicle and keep the driver up to-date with his surroundings.

Tuohy et al. [39] explore the physical layer technologies for Next Generation Ethernet networks with some middleware technologies in terms of automotive industries. They also categorise automotive network traffic and classify it with respect to control data, safety data, infotainment data and driver assistance cameras. Control data is further divided into low-bandwidth control applications and real-time control applications. Systems that control non-safety critical aspects of the vehicle such as electronically controlled mirrors and seats fall into the category of low-bandwidth control applications, while suspension and braking systems, ABS and traction control lie under real-time control applications. Safety data assists drivers by using the built-in driver safety systems such as adaptive cruise control, parking sensors and night-time pedestrian detection infrared sensors. GPS, audio and visual entertainment, and on-board internet facilities fall into the category of infotainment data that encompasses all the traffic related to entertainment and driver information systems within the vehicle. Finally, the driver assistance cameras assist the drivers while reversing and lane departing [39]. The authors conclude their discussion by suggesting the standardisation of approaches across the industries, allowing manufacturers to focus on new innovations based on existing applications.

Similarly, Saed et al. [40] address the security issues in intra-inter vehicle communication networks. In terms of intra-vehicle communication, the authors suggest that data transmission between the vehicle's Electronic Control Units through a Controller Area Network (CAN) protocol should be protected. The research was carried out to present some background study into the specifics of CAN applications. Some of the key issues such as boot loader, privacy, operating system level issues, application specific issues and communication related issues with respect to security not only in today's vehicles but also in the future vehicles were focused. Promises of security improvements for future vehicles are also suggested such as adopting IPV6 in the vehicle communication protocol, behavioural privacy, cross-domain security, use of public key infrastructure, resolving privacy concerns with respect to customer information, implementing a robust security approach for the vehicle communication and last but not least addressing all the newly identified vulnerabilities by constant monitoring and tracking [40].

### E. Challenges of existing communication technologies and solutions

Some of the major standardised technologies that are currently being considered for V2X communication are: IEEE802.11p/DSRC and its extension IEEE802.11px, 3rd generation partnership project (3GPP)'s Long Term Evolution-Advanced (LTE-A) Pro and millimetre-wave (mmWave) [41, 42]. Further detail about each of these technology with respect to its pros and cons is provided below.

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TABLE II: Candidate Technologies for V2X Communication

| Features | Candidate Technologies | | | |
|---|---|---|---|---|
| | IEEE802.11p/DSRC | IEEE802.11px | LTE-A Pro | mmWave |
| Frequency Band | 5.85-5.925 GHz | 5.85-5.925 GHz | 5.72-5.75 GHz | 57.05-64 GHz |
| Channel Width | 10 MHz | 10 MHz | Up to 640 MHz | 2.16 GHz |
| Range | 1 Km | 1 Km | 30 Km | 50 m |
| Bit Rate | 3-27 Mbps | Up to 60 Mbps | Up to 3 Gbps | Up to 7 Gbps |
| Latency | 10 ms | 10 ms | 20-80 ms | 10 ms |
| Coverage | Intermittent | Intermittent | Ubiquitous | Intermittent |
| Broadcast Support | Yes | Yes | Yes | No |
| V2I Support | Yes | Yes | Yes | Yes |
| V2V Support | Yes | Yes | Over PC5 | Yes |
| Relay Mode | Yes | Yes | Yes | Yes |
| MIMO | Yes | Yes | Yes | Yes |

*1) IEEE802.11p/DSRC and IEEE802.11px*

The IEEE802.11p/DSRC standard incorporates the suite of IEEE802.11s and IEEEP1609.x standards (with some modifications), operating in a frequency range of 5.850 GHz to 5.925 GHz. Having a decentralised architecture, the Physical (PHY) layer of the protocol is based on Orthogonal Frequency Division Multiplexing (OFDM), while the MAC layer is based on Enhanced Distributed Channel Access protocol having Carrier Sense Multiple Access with Collision Avoidance and four different access categories to the medium that supports different QoS profiles and prioritises data traffic [41, 42]. Due to a direct communication between the source and destination endpoints, the protocol can operate without network coverage in a fully distributed manner. These endpoints start communication without forming a Basic Service Set that allows vehicles to effectively and immediately transmit data. The protocol spectrum is divided into seven channels each of 10 MHz bandwidth, where the control channel is specifically reserved for broadcasting safety and mission critical messages, while the remaining six channels can be used for all other applications [42].

Due to the adopted MAC contention based medium access strategy, the IEEE802.11p/DSRC throughput and end-to-end delay performance degrades quickly as the network load increases. The main reason behind this degradation is the lack of coordination between the devices and the use of a "listen before talk" mechanism. Based on these assumptions, the protocol may only be suitable for transferring low bitrate data streams in vehicular environments. Another drawback of IEEE802.11p/DSRC is that its communication range typically extends to several 100s of meters and that may not be applicable to some V2X applications where a reliable transmission beyond this communication range is required [41]. Efficient utilisation of the allocated spectrum for mission critical applications and safety purposes in 5.9 GHz frequency band is another drawback of IEEE802.11p/DSRC.

According to Mavromatis et al. [42], to overcome the deficiencies of IEEE02.11p/DSRC, an enhanced version of the protocol in terms of IEEE802.11px is launched based on a Space Time Block Coding mechanism that can increase the performance under noisy channel transmissions and can improve the packet delivery rate by 40% as compared to IEEE802.11p. Also, the new protocol is expected to provide MIMO antenna capabilities with improved OFDM layouts, and very high throughput frame by enhancing the channel capacity by a factor of 10 Mavromatis et al. [42].

*2) 3GPP LTE-Advanced Pro*

The next level of communication is to bypass the existing infrastructure and transfer data directly between the users. It's basically the next generation of Device-to-Device (D2D) communication where an infrastructure independent communication will be offered with significantly lower delay performance. LTE and LTE-A Pro, represents the next generation of 5G cellular communication standards defined by 3GPP in order to provide high data rates, pervasive coverage, enhanced connectivity for end-users regardless of the geographical location and environment. Public Land Mobile Network facilitates cellular radio coverage to vehicles and vulnerable road users such as pedestrians and cyclists based on 3GPP LTE standard also known as Evolved Universal Terrestrial Access Network and can exploit the existing infrastructure for V2X communication [41, 42]. LTE was originally designed for mobile broadband (MBB) services; hence it has many limitations with respect to V2X communication. Some of those limitations are listed as follows based on [41]:

- Latency increases as the number of users in a cell increases, and to maintain a latency below 200ms, event-triggered messages should be limited from 100 to 150

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devices in rural and urban environments respectively.
- A single data packet between two vehicles needs to traverse the entire network rather than a direct transfer link between the source and destination. This may lead to a higher delay and sometimes a point of failure for the infrastructure.
- LTE will not be an optimal solution for transmitting small chunks of data as it was originally designed for broadband services. Transmission of these small packets of data may lead to problems such as channel coding, control and channel estimation overhead and resource granularity.
- As LTE is an infrastructure-based approach, it may be difficult to satisfy the coverage requirements in tunnels, mountainous territories, underground parking and rural areas etc. which are basically the most vulnerable places for road-users.

To overcome these limitations, the current release of LTE-A Pro is designed in such a way that can fulfil almost all the requirements for public safety and commercial consumer applications such as higher mobility and long-distance coverage, enhanced QoS, and multicast communication. Similarly, the downlink and uplink access technologies are based on OFDMA and Single Carrier (SC-FDMA) respectively, so frequency-time resource scheduling is guaranteed with higher flexibility and efficiency. Even with dynamic propagation environments and higher mobility speeds, significant spectral efficiency can be obtained based on advanced MIMO capabilities. Also, having multicast/broadcast capabilities, LTE-A Pro can fully support vehicular service message broadcasting in cross traffic assistance applications. With such mature capabilities, LTE-A Pro still has limitations in terms of latency [43, 44]. The maximum achievable latency in end-to-end communication can be as high as 80ms, which is not sufficient to support tactile-like communication that requires a latency of less than 10ms. Similarly, terminals need to re-establish a connection with the base station after an idle state costing a latency of almost 110ms for additional link establishment, which again promotes severe performance degradation and may not be usable in safety-critical applications [45].

#### 3) Millimetre Wave (mmWave)

The next generation of 5G cellular systems will have mmWave technology and systems that will be based on this technology will play an important role in 5G communication. mmWave operates in the spectrum between 30GHz and 300GHz, while the carrier frequencies are spread around 60GHz with a channelisation of 2.16GHz. Through beamforming technologies, mmWave will achieve high array gains by implementing large antenna arrays that will help the system to achieve higher data rates typically up to several gigabits-per-second [42, 46]. IEEE802.11ad which is basically a protocol stack for mmWave will ensure a data-rate of 7Gbps with an end-to-end latency of less than 10ms. Also, under ideal propagation conditions, mmWave systems outperforms IEEE802.11p/DSRC and LTE/LTE-A Pro standards in terms of V2X communication [47]. A summary of all these features along with some additional capabilities of the above mentioned technologies is given in Table II based on [42].

## IV. Drones

Wireless networks comprising of Drones/UAVs can provide on-the-fly communication facilities in a cost-effective way in situations where part of the existing terrestrial infrastructure is destroyed and there is a need to provide emergency services and avoid any further destruction in the disaster-struck areas [48, 49]. In most cases, UAVs are only used for military purposes, but when they are equipped with small access points/routers, they can provide a communication bridge between ground users and network nodes. Similarly, UAVs can be used in package delivery, surveillance operations and IoT applications. Surveillance operations usually involve monitoring the areas of interest over a long period of time. Such operations may include search and rescue operations, border patrol and traffic monitoring, fire monitoring and many more [49, 50].

### A. Single UAV Deployment

Single UAV deployment is a simple scenario where a UAV tries to bridge communication between two static nodes on the ground. Kwon and Hailes [51] proposed a greedy search algorithm in order to search the area for node discovery and to achieve optimum communication between the participating nodes. The optimal position of a UAV is identified based on balanced signal-to-noise ratio (SNR), throughput, and bit error rate. SNR and throughput are used as input variables and based on these variables the proportional-integral-derivative controller decides the next waypoint of the UAV. The authors concluded that based on SNR and throughput, the algorithm can calculate the most advantageous position of the UAV where all the participating nodes can be served at the same time.

Similarly, several algorithms have been developed in order to connect a disjoint group of nodes using a single UAV. Heimfarth and de Araujo [52] presented a method for connecting a disjoint group of wireless sensor networks with the help of a UAV for the purpose of carrying messages. The authors used the UAV as a data mule, where the UAV physically transmits the packets to the entire network. Initially the network was partitioned into different segments and a cluster head election was done in order to elect a cluster head for each group of nodes. The cluster head is the node that is responsible for communicating and exchanging data with UAV. The authors proposed a separate algorithm for the cluster head election process. Within a segment, geographic routing was used to route the packets and was termed as intra-segment message relay. For inter-segment message relays where the packets need to be transferred from one segment to another, the UAV visits each cluster head for collecting data and delivering it to the required destination. The authors performed different simulations and concluded that the system is capable of maintaining communication between the group of nodes with a low packet rate for a moderate set of traffic. Two different cases were considered for simulation purpose having an area of 4 and 9 km2 respectively. 6 & 9 segments with 60 nodes per segment using a single UAV with a speed of 60 km/h having a buffer size of 200-400 packets was considered

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for the same set of simulation. The authors also noticed a bigger latency in the case of a huge deployment area [52].

An intelligent hierarchical state routing algorithm (IHSR) was proposed in order to reduce the system latency because of long propagation delays of UAVs as well as to improve the throughput [53]. The hierarchical infrastructure of a heterogeneous ad-hoc wireless network with UAVs consisted of 2 levels i.e. ground ad-hoc wireless network, and ground embedded mobile backbone network. IHSR first divides the entire network into clusters where each cluster has its own cluster head and cluster internal nodes (cluster members). Logical addresses were introduced in IHSR in order to manage the mobility in a better way. For route discovery, link state messages or invitation messages were exchanged locally and globally through neighbour cluster heads and UAV broadcasts. In respond to an invitation message, each lower level node sends a registration message to the cluster head where the cluster head stores it in its INtable. The authors verified their algorithm through different simulations and concluded that the proposed system improved the throughput for link state routing through UAV broadcasts instead of flooding [53]. Moreover, different mobility models for ad-hoc network were studied by [54]. The authors categorised the movement of mobile nodes in two different models i.e. Entity mobility models, and Group mobility models. In entity mobility models, the movement of mobile nodes are independent of each other, while in group mobility models, the movement of mobile nodes are dependent on each other.

### B. Multiple UAV Deployment

Complex situations occur when a single UAV is unable to cover a group of nodes in a specific mission. Multiple UAVs are used in such cases in order to cover a set of nodes in a bounded region. A cooperative distributed planning algorithm termed as the consensus based bundle algorithm (CBBA) was proposed by Ponda et al. [55] in order to ensure network connectivity with limited communication facilities for a group of heterogeneous agents operating in a dynamic environment. The algorithm improves the entire mission performance and also extend the range of a team. CBBA use the free agents as relays for maintaining connectivity between the base station and UAVs during the task execution. The authors validated the performance of CBBA through simulation results as well as field tests and, based on those results they concluded that CBBA is well suited for real time applications. Similarly, Palat et al. [56] studied the application of distributed MIMO schemes on multiple UAVs as communication relays for range and reliability improvement of ground based ad-hoc networks. The authors used different simulation parameters to verify the performance of both MIMO and orthogonal space-time block codes techniques under ideal and non-ideal conditions. In the case of lower carrier frequencies, better performance can be achieved in terms of distributed beamforming. Also, in the case of multi-hop relaying based on swarm of UAVs, the range and reliability of ad-hoc networks can be improved.

### C. Collision Avoidance in the case of multiple UAVs

Collision avoidance is another important issue that must be addressed in the presence of multiple UAVs. Li et al. [57] have evaluated a number of collision avoidance algorithms such as collision cone, geometric collision cones, simulated annealing, inverse proportional navigation, artificial potential fields, and dynamic sparse A-Star (A*). The authors verified the evaluation process by implementing and simulating the aforementioned algorithms on a common infrastructure, and also addressed the strength and weaknesses of each approach. Collision cone and geometric collision cone algorithms works on the concept of relative velocities of all UAVs generating a collision cone. A minimum distance between two UAVs was calculated based on the relative velocities and concluded that if the relative velocity is greater than a specified degree of angle, then the UAVs are moving away and there is no threat of collision. On the other hand, if both the UAVs are inside the cone and their relative velocities are less than the specified degree of angle, a threat of collision is there. In that case, the relative velocities of UAVs need to be changed in order to rectify the possible collision. Moreover, if both the velocities are same, then there is a need to deviate the UAV from their original path, because they are approaching towards each other and there is a possibility of entering into the threat zone.

In simulated annealing, there are three main steps i.e. clustering the UAVs, establishing a cost function, and minimizing the cost function. In step one, the UAVs are clustered into groups based on their threats. Also, a minimum distance between two UAVs where the UAVs can still avoid the collision is calculated and this particular area is termed as danger zone. If there is no threat in the danger zone, the UAV can safely continue towards its goal. A cost function is then established where the UAVs will be instructed regarding how much they will turn in order to change the velocity and to avoid collision. This cost function is then minimized based on certain parameters such as energy level of the current state, and random neighbouring state for new solution. The authors concluded that the neighbour can become a new solution only if the energy level is less than the current solution, or if the probability function designates it as the new solution [57].

### D. Drone Applications using 5G

Lin et al. [58] performed field measurements for data collection during drone flights connected to the commercial LTE network. They also performed some simulations in order to study the performance of network in terms of serving many drones simultaneously over a wide area. The main purpose of this study was to analyse the applicability and performance of mobile network connectivity to low altitude drones. The authors conclude that the current mobile LTE network can support the initial deployment of low altitude drones, but they are still facing some issues with respect to interference and mobility that can be addressed by the next generation of 5G networks by providing more efficient connectivity for wide-scale drone deployment [58]. Similarly, Luo et al. [59] highlight the communication and network technologies that can contribute to UAV disaster management systems in

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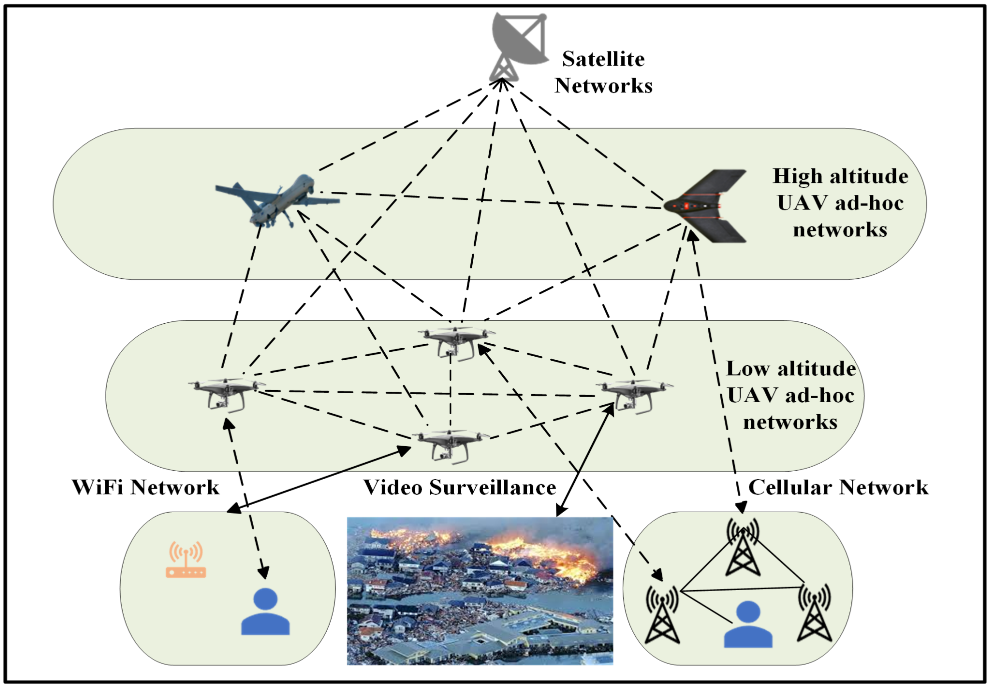


Fig. 4: UAV-based disaster management

situations including early warning system, search and rescue , data gathering, provision of network coverage in emergency communication and logistic delivery. The authors also address the networking technologies that are essential for UAV deployment in practical environments in the context of disaster management and response. A universal network architecture based on 802.11 Wi-Fi network, 2G/3G/4G cellular network, UAV ad-hoc network and satellite network was proposed as shown in Figure 4.

Design considerations and challenges such as bandwidth consumption, transmission latency and disruption of UAV-based wireless network for disaster management were also studied. In terms of bandwidth consumption, strict bandwidth requirements must be fulfilled especially for online applications such as real-time monitoring. In addition to real-time monitoring, 4K or even 8K videos captured during aerial monitoring applications require a much higher bandwidth. Such a higher bandwidth can be ensured by the next generation of 5G communication. Latency is another important aspect in the design of system components and network protocols. For real-time visual and audio data transfer in the context of aerial communication, latency should not be more than 50-100ms. Similarly, for surveillance, such as border or highway patrolling, the latency should not be more than 3ms. The authors also address the design considerations and challenges such as channel modelling, antenna structure design, UAV cooperation, advanced data analytics, path planning, and energy efficiency etc. of a UAV-based ad-hoc network for disaster management [59].

Moreover, Huo et al. [60] present a comprehensive review of the current developments made in three categories of UAV-enabled next generation wireless communications. In the first phase, a multi-layer distributed UAV-enabled 5G network is proposed, where the architecture is more flexible, hierarchical and supports scenario driven reconfigurations. In the second phase, several performance enhancement enablers are identified and evaluated for UAV-enabled 5G wireless communications. Furthermore, Naqvi et al. [48] focus on different UAV-enabled 5G communication paradigms such as deployment issues related to energy efficiency etc. In this regard, the work investigates the compatibility of UAVs with traditional wireless networks to achieve energy efficient high data rates for 5G communications. Moreover, the article proposes a UAV-based routing protocol for disaster-resilient infrastructure. A case study is presented based on a UAV that is incorporated in a wireless network in both low and high-power base stations operating at different frequencies. The study concludes that the incorporation of UAVs will increase the performance of the heterogeneous network in terms of network coverage and data rate.

Similarly, He et al. [61] discussed the security aspects of UAV-enabled 5G communication for public safety networks. Using UAVs in such a critical network infrastructure may pose cybersecurity threats to the personal information of the individuals involved. If UAV-enabled communication is not made secure, this will reduce the applicability and usability of such networks. The authors claim that UAV-enabled communication networks suffer from issues like unauthorised access, malicious control, or other cybersecurity attacks. The authors emphasise the need for communication security schemes to be incorpo-

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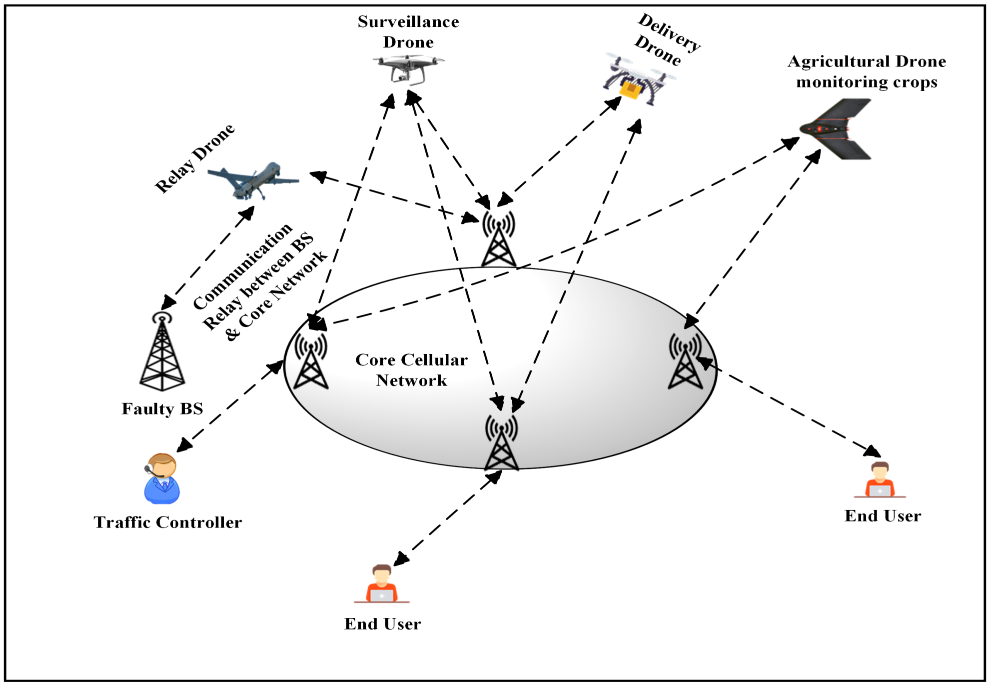


Fig. 5: An overview of cellular-connected UAVs representing different use-cases

rated in such critical networks to secure personal information [61]. Shakhatreh et al. [8] performed a comprehensive survey on UAV civil applications with their key challenges. The main purpose of the study was to present the worldwide UAV payload market value and to provide a classification of UAVs based on certain factors such as endurance, weight, coverage range, maximum altitude, and its applications. The authors also discussed the civil applications of UAVs in a number of key areas including real-time monitoring of road traffic, security and surveillance, precision agriculture, provision of civil infrastructure, search and rescue operations, and delivery of goods along with their key challenges.

Additionally, Fotouhi et al. [62] proposed a novel Drone-Cells scenario where the drones within a cell persistently move in order to serve the users from a closer distance for the sake of improving the spectral efficiency of the network along with the quality of service of the cell-edge users. Three different mobility control algorithms with erratic complexity and performance were used to check the efficiency of DroneCells scenario. Based on the simulation results, the authors claimed 34% improvement in terms of spectral efficiency and a 50% increase in the 5th-percentile packet throughput as compared to drone hover over some fixed locations. The authors also assured that such kind of results can be obtained with minimal drone speeds in order to avoid any negative effect on drone battery lifetime [62].

Likewise, in [63], the authors provide an overview of the emerging technologies with their potential benefits, communication and spectrum requirements, along with proposing some new design considerations with respect to the next generation of three-dimensional heterogeneous wireless networks. Based on the proposed cellular-connected UAV technology as shown in Figure 5, new wireless technologies can be developed that will enable significantly enhanced UAV-ground communications. Several appealing advantages of cellular-connected UAVs such as ubiquitous accessibility, enhanced performance, ease of monitoring and management, robust navigation, and cost effectiveness were also highlighted. In terms of new design considerations, the authors explored 3D coverage, unique channel characteristics, severe aerial-ground interference, and asymmetric uplink/downlink traffic requirements. Similarly, in terms of promising technologies that can effectively enable future wireless systems, the authors investigated 3D beamforming, multi-cell cooperation, and ground-aerial non-orthogonal multiple access. Finally, the authors outlined some future directions such as quality of service aware trajectory design, millimetre wave cellular-connected UAV, and cellular-connected UAV swarm [63].

In similar manner, [64] studied the PHY layer security in UAV communication to address the two critical issues i.e. the achievable secrecy rate between the legitimate transmitter and intended receiver will be limited as compare to the rate between the legitimate transmitter and eavesdropper, even in the presence of power control, articial noise, cooperative jamming, and multi-antenna beamforming techniques. Secondly, since the eavesdropper is a passive device, it is quite difficult to estimate the channel state information of the eavesdropper that is usually required to a legitimate transmitter. For simplicity, the authors considered a single UAV that is deployed to send the confidential information to a fixed position-based

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TABLE III: Characteristics of Cellular Technologies in Disaster Management using Drones

| Features | Cellular Technologies | | | | | |
|---|---|---|---|---|---|---|
| | WiFi | GPS | UMTS | LTE | LTE-A | 5G |
| Frequency Band | 2.4 GHz, 5.2 GHz | 1176-1576 MHz | 700-2600 MHz | 700-2690 MHz | 450 MHz- 4.99 GHz | 57.05-64 GHz |
| Channel Width | 20 MHz | 2 MHz | 5 MHz | 1.4, 3, 5, 10, 15, 20 MHz | Up to 100 MHz | 2.16 GHz |
| Range | 100 m | _ | 10 Km | 30 Km | 30 Km | 50 m |
| Bit Rate | 6-54 Mbps | 50 bps | 2 Mbps | Up to 300 Mbps | Up to 1 Gbps | Up to 4 Gbps |
| Latency | 10 ms | 10 ms | 20-80 ms | 10 ms | _ | _ |
| Coverage | Intermittent | Ubiquitous | Ubiquitous | Ubiquitous | Ubiquitous | Ubiquitous |
| Broadcast Support | Broadcast | Broadcast | MBMS | eMBMS | eMBMS | eMBMS |
| Mobility Support | Low | Extremely high | High | Very high (350km/h) | Very high (350km/h) | Ultra-high |
| UAV Support | Yes | Yes | Potential | Potential | Potential | Potential |

legitimate receiver in the presence of a fixed position-based eavesdropper. The main purpose of the study was to maximise the average secrecy rate of the UAV by jointly designing the UAV trajectory and transmit power control subject to different constraints such as average and peak transmit power, UAV mobility with its maximum speed, and initial and final UAV locations. Based on the proposed efficient iterative algorithm, the authors concluded that the algorithm can expressively improve the physical layer security performance of the UAV communication system.

### E. Comparative Analysis of Control Latency in terms of 4G and 5G

In this section we elaborate on the control latency that is currently offered by different cellular technologies for mission critical infrastructures using drones and how 5G will help to reduce that latency. Also, we discuss some of the capabilities that 5G is offering for drones. Yang et al. [65] performed some field experiments in order to gain insights into the capabilities of 4G networks for connected drones. The results were collected at 2.6GHz carrier frequency with 20MHz carrier bandwidth using LTE-Advance network. Latency performance of the proposed network was calculated at three different heights i.e. 50m, 100m, and 300m. The results illustrate that most of the latency data samples are concentrated between 200ms and 300ms at a height of 50 and 100m respectively, while at 300m height, the latency data samples are more inclined towards 400 to 500ms. Based on the latency samples, it can be suggested that without further enhancements the current LTE-A network might have difficulties in serving drone applications with rigorous latency requirements. The authors conclude that the more powerful capabilities of the next generation of 5G networks can address the coverage, data rate, and latency issues of the existing technologies and can fulfil the objectives of the connected drones in mission critical infrastructures [65]. The improved capabilities of 5G networks may include coverage enhancements and high data rates, service differentiation and QoS enhancements, and detection and resource management. Some of the key characteristics of cellular communication technologies with respect to disaster management are summarised in Table III [59].

## V. Healthcare

With the increase in the world's adult population [66], there is an increasing requirement for treatment and assistance in emergency healthcare situations. This has emphasised the need for technological advancements in healthcare to provide efficient and affordable solutions to an increasing number of patients. In [67], the authors identified the important features that a mobile healthcare system should possess. Such a system should be able to (i) handle emergency cases using tele-medicine facilities, (ii) provide tele-medicine unit to a doctor in order to enhance intensive healthcare provision and (iii) allow the installation of a tele-monitoring system at patient's home while the monitoring station is based in the doctor's office. [68] provides a survey of healthcare applications that deploy wireless sensor networks such as movement tracking, medication intake tracking and daily activity monitoring. The authors emphasise that there are several limitations that currently exist in current technologies that can be overcome by adopting 5G networks to make healthcare remotely accessible.

Soldani et al. [69] propose a framework that can be deployed on mobile devices, offering functionality for collecting, processing and storing information to support identification of abnormal events. The development of 4G technologies enabled the advent of a range of tele-medicine applications such as remote consultation, remote surgery and patient monitoring. Kumar et al. [67] also discuss limitations of existing technologies (i.e. lack of flexible and compatible tele-medical links due to high hardware and operational costs, data transfer rates and latency) that will need to be addressed in future technologies

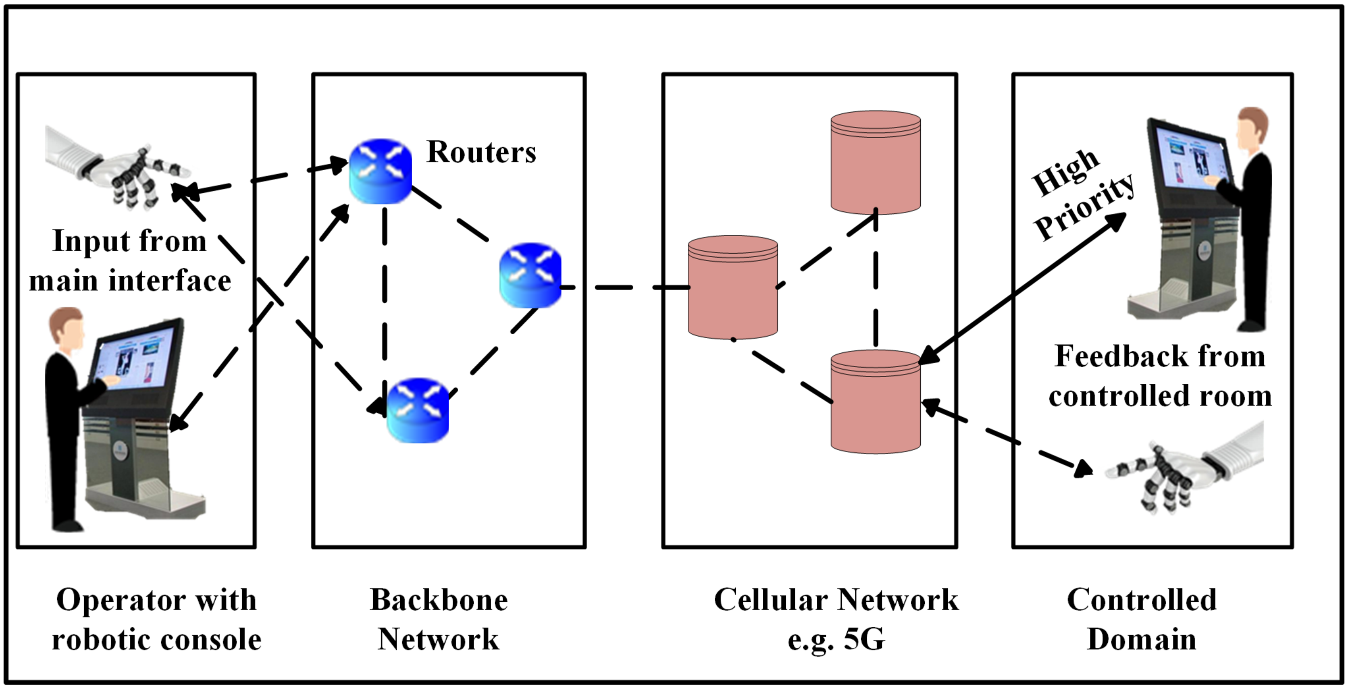


Fig. 6: A representation of a tele-medicine infrastructure using 5G network

such as 5G. When deploying the next generation of networks, the main factors that should be addressed are security, seamless integration, QoS and streaming and compression issues.

It is expected that the advent of 5G technologies will play an active part in providing patient-oriented healthcare applications which can be easily managed by the patient or the carer. It is expected that 5G networks would carry a significantly higher volume of data while maintaining reliability [70, 71]. The critical requirement for 5G networks is ultra-low latency which will allow the deployment of mission critical applications such as tele-consulting, tele-surgery etc. Kim et al. [72], highlight that in order to achieve interdisciplinary collaboration between medical services and technology, there are a few requirements to be met. These include (i) sensors that are ultra sensitive and small enough to be embedded into the patient's body, (ii) ultra reliable low latency communications infrastructure which can transmit large amounts of audio, video and haptic feedback data with very little delay; and (iii) standardised haptic interfaces such as surgical robots etc. that will possibly increase the type of applications where such technologies can be deployed. Figure 6 represents an infrastructure model for a tele-medicine system which consists of an operator with an interface at the controller end connected to a remotely controlled domain via a 5G cellular network.

De Mattos and Gondim [73] discuss the requirements for implementing mobile health applications (m-health) using 5G networks and the capabilities of 5G communication that are important for m-health applications. The authors identified some of the significant features such as very low latency, bandwidth, scalability, high network capacity, large number of sensory devices, long battery lifetime, reliability, resilience and security that 5G networks require for m-health applications. Chen et al. [70] and Thuemmler et al. [74] discuss the various technical specifications relevant to healthcare such as network design approaches and paradigms. The various aspects discussed range from the types of data sources available from the healthcare domain, to the techniques required to perform the necessary data processing and network resource management techniques. In [74], the authors discuss the network spectrum required for tele-medicine applications and the interoperability requirements when setting up a tele-medicine infrastructure. [10, 75–77] refer to IoT devices used for healthcare applications as Internet of Medical Things (IoMT) which requires high data and speed capacity and a long operation time over a reliable network with very low transmission delay.

[78] provides a survey of the various technological trends in the realm of 5G networks and various IoMT applications and the requirements of 5G networks for the deployment of these systems. Darrell M. West [10] discusses the capabilities of 5G as compared to existing networks to deploy cyber-physical healthcare systems and could allow for implementation of healthcare applications such as online consultation, diagnosis and remote surgery applications. The following sub-sections go into further details of the popular healthcare applications available which could benefit from incorporating 5G networks for communication [76, 79].

### A. *Online Consultation*

5G technology with IoMT, big data analysis and ML techniques will allow for enhancements in healthcare applications [11]. The incorportaion of sensors as part of IoMT and 5G network to monitor vitals and other health related data will allow patients (at home) to monitor themselves and transmit the data to the health expert at a remote location (i.e. hospital) for a real-time online consultation. In [80], the authors identify the advantages of using online consultation and also propose a platform for online consultations. They emphasise that the online consultation can provide better regulatory governance which would ensure transparency in the regulatory environment. They highlight the drawbacks of current online consultation systems which lack coordinated information exchange. They do emphasise that the existing global communication network provides an opportunity to construct a communication platform for online consultations where ordinary citizens, experts, different civic and business associations and executive bodies could contribute and exchange information using mainly standard internet connectivity [80]. Segura-Sampedro et al. [81] conducted a study on postoperative wound observation via remote access. The findings suggested that the patients were satisfied with this method of consultation and considered it to be feasible and safe for postoperative applications.

### *B. Online Health Monitoring*

With the advent of 5G technologies, it is possible to realise the concept of virtual hospitals which provide a variety of services over a communication channel. In [82], the authors addressed security and privacy issues that need to be considered when implementing a health monitoring application in the 5G communication context. Limitations of the existing cellular technologies with respect to body area network were highlighted and possible solutions based on some new approaches in terms of 5G were also proposed. Biswas and Misra [83] discuss low cost, reliable e-Health monitoring device using an IoT-based platform architecture that can measure the vital signs of an individual, securely store the data on a server and analyse the data to generate specific proactive alerts when necessary. The platform connects the patient to the registered doctors who will have access to the patient's health data which are monitored using medical sensors. Hence, the platform can be used to provide clinical healthcare at a distance, thus enabling the monitoring of elderly or home bound patients and those who are located in remote areas. Jusak et al. [77] propose an IoMT system for monitoring cardiac signals using an agent and manager model. The agent collects the signals in the form of a phonocardiograph signal which is then sent to the manager which gathers the health data and presents it to the healthcare providers via a web interface. This model can be extended to other types of monitoring application where the patient data can be accessed securely from any location in the world by a doctor or healthcare provider.

### *C. Remote Diagnosis*

Darrell M. West [10] discusses the potential of using 5G networks to deploy remote healthcare systems that would allow for real-time monitoring and management of several sources of health data and efficiently diagnose an ailment event before it manifests. Brito [78] summarises IoT and related e-health applications which include medical expertise using advanced tele-diagnostic tools, enabling remote physical examination (even by touch) through a robot that is remotely controlled, which can offer audio-visual and haptic feedback. The authors identify the requirements that enable such applications to be implemented, including enhanced mobile broadband, millimeter wave communication and low latency high reliable communications. Chen et al. [84] propose a 5G-Smart Diabetes system, which combines state-of-the-art technologies such as wearable 2.0, ML and big data to generate comprehensive sensing and analysis for patients suffering from diabetes. They also present the data sharing mechanism and personalised data analysis model for 5G-Smart Diabetes. Bagula et al. [85] details a cyber-physical healthcare system which allows for recognition of a patient's condition that is considered at the first step in a fully digitised remote healthcare system. ML is used in the multi-layer framework that consists of numerous low cost lightweight devices.

### *D. Mobile Robotic Surgery*

With the advancement of 5G technologies, the popularity of mobile robotic surgery is set to grow substantially [86]. Haptic sensing is an essential requirement for an efficient remote surgical procedure to be conducted. Lema et al. [87] tested a tele surgery system which implements a tactile glove to provide haptic feedback and observed how it could improve the performance of remote surgery applications. The performance of robotic tele-surgery depends on various properties of the communication network such as latency, jitter and packet loss; which is considered significant when the remote surgery system is implemented with haptic feedback. This highlights the significant challenges that need to be addressed in order to use a reliable and secure but cost-effective communication setup for remote/robotic surgery applications [88].

Surgical robots will provide an alternative to maintain the high quality of personal and medical care in Europe, where remotely operated devices would allow the healthcare system to operate at a much higher performance and cost-effectiveness. To reduce the performance degradation resulting from large latencies, the operator needs to be within the proximity of the remote site. Implementing 5G technologies would reduce the latency issues which would improve the access to mobile robotic surgery.

## VI. Open Research Challenges and Future Directions

In this section, we shed light on some of the open research challenges in terms of V2X, drones and healthcare and highlight interesting research topics for future directions. A list of potential research challenges along with their future directions is listed below.

- Path loss and channel model of higher carrier frequencies is a challenging issue specially in areas surrounded by skyscraper buildings and having a denser base-station deployment.

- Latency of less than 1 millisecond in emergency situations for autonomous cars and automatic pilot is an important issue that needs to be ensured in the future cellular technologies.
- Ultra-reliable communication is another open issue that needs to be addressed in the future for both vehicle and public safety. A lot of work has already been done in this area, but still with the introduction of IoT and massive number of connected devices will make it a challenging issue again.
- Another important issue that needs to be researched is the identification of vulnerabilities and security loopholes in the new communication system. A tremendous amount of work is required at physical layer to identify the suitable techniques to cope with the compromised user equipment and data. Effective use of ML techniques to analyse and differentiate between normal and attacker behaviours is also a research challenge.
- Similarly, in terms of V2P, the response time and detection of vulnerable road users by a self-driving car is a challenging issue that needs to be explored.
- In terms of drones, The main problem with UAV/drone communication is the energy limitation. It becomes more critical in situations like disaster management and mission critical infrastructures. A lot of work has been done in battery technologies but still there are gaps that needs to be addressed in the future by using beamforming techniques.
- Latency and reliability are the two main factors that needs to be ensured in UAV operations such as search and rescue, fire monitoring etc. in order to help the rescue teams and safeguard the survivors. Continuous video streaming in disaster situation needs a reliable connection between UAV and ground stations. Assurance of a reliable link will require ultra-low latency and ultra-high reliability that can be addressed in the next generation of cellular communication.
- Security and privacy problems such as eavesdropping, jamming and spoofing in aerial networks is another challenge in UAV communication. Lightweight techniques and AI solutions can be used to address these issues.
- Mobility support and collision avoidance in terms of Internet of UAVs are some of the other challenges that need to be researched in the future.
- Finally, in terms of healthcare, online consultation, robotic surgery and telemedicine requires a network that can support high-definition video streaming. In such cases ultra-low latency of less than 10ms and ultra-high reliable connection are required. Latency of less than 10ms is a critical challenge and an open research problem in future cellular communication.
- Reliable and real-time remote monitoring requires a high speed network and a reliable connection, otherwise practitioners will be unable to get the real-time data that can be used for quick and on-time healthcare decisions. Providing higher bandwidth and reliable connections are still an open problem that need to be addressed in future cellular networks.
- Integration of AI techniques for potential diagnosis (in the healthcare sector) that can lead to the best treatment plan is also a research area that needs to be explored.

## VII. Conclusions

In this paper, we have explored 5G use-cases emphasising on three main case studies: V2X communication, Drones, and Healthcare in order to identify the most challenging use-case for our future work. Starting with V2X communication, we explored V2V, V2P, V2I, and IV Communication along with their application areas. We also addressed the limitations and challenges of the existing communication technologies and proposed solutions based on 5G technologies. We further studied drone communication for mission critical infrastructures and provide a comparative analysis of 4G (LTE/LTE-A) and 5G with respect to control latency. Moreover, we examined healthcare with respect to 4G and 5G technologies and provide an overview of online consultation, online health monitoring, remote diagnosis, and mobile robotic surgery. Based on the literature review and critical analysis, we have concluded that drone communication for the provision and maintenance of critical infrastructures is the most challenging scenario that can be carried to the next phase of our work.

In the future, we are planning to extend this work and propose to identify tools in which we can simulate our initial models in order to validate them and check their applicability for real-time applications. We also look forward to implementing the model in a real-time testbed. The potential impact on standard bodies along with community benefits is also part of our future plans.

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